SIMULATION OF IRRIGATION NETWORKS: CASE OF WALAWE BASIN IN SRI LANKA

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ABSTRACT

A computational model was developed to simulate the water resources and irrigation systems of a large region within the Walawe river basin in Sri Lanka. This simulation incorporates the hydrological processes, the water demands and the irrigation system. The simulation uses a time step of a month. Various cropping patterns in the cultivated lands were investigated. Several rule curves for the operation of the major reservoir in the catchment, the Udawalawe was investigated. An optimal reservoir operating policy was developed for the cultivation of paddy from 40% to 80% of the irrigable area and diversified crops in the remainder. All of these estimates were incorporated into the simulation. The model predicted the reservoir releases from the main reservoir with an error limited to 10-30 % for the period 1990-1994.

INTRODUCTION

The use of computer simulation models in water resources systems is useful in the assessment and prediction of water use and design of irrigation works. Models can be used to assess the effectiveness of alternative reservoir operating policies and cropping pattern, to assess the impact of deforestation, climate changes and droughts and to assess the viability of augmenting the irrigation system

The United States Army Corps of Engineers have already developed a sophisticated water resources model named as HEC. This model however relies on uniform availability of hydrological data. One is not certain as to whether the approximations made in this software will suit the conditions in Sri Lanka. The Irrigation Department of Sri Lanka has developed guidelines for assessment of hydrological parameters in Sri Lanka. These guidelines can be explicitly incorporated into a new model. Dharmasena (1991, 1994) has built simulations of river basins such as the Kelani using the Fortran language. However, no work has been reported on the Walawe basin or on the use of simulation packages. SIMULINK, which is a simulation toolbox for the Matlab mathematical package, is used in the work reported here. A Simulink model can be easily expanded as it is based on a graphical user interface for constructing block diagram models using drag-and-drop operations.

The objective of this paper is to demonstrate the viability of simulation using the Department of Irrigation guidelines under typical limitations as in Sri Lanka. The case study that is used is the Walawe irrigation project where the first author served as a trainee at the Mahaweli Economic Agency (MEA) at Embilipitya during 1994.

The Walawe river lies in both the south-west and north-east monsoon zones. It originates from Adam's Peak and discharges to the sea 136 km away at Ambalanota. It conveys about 1500 MCM of water annually. 574 square kilometres of the upper reaches of the Walawe basin is in the wet zone (Domroes, 1974) with an average annual rainfall of 3680 mm. The lower reaches of the Walawe basin of 1870 square kilometres falls in the dry zone and the rainfall drops to 1120 mm per annum (Arumugam, 1969). The Walawe carries the southwest monsoon rainwater to the dry zone.

From ancient times, a system of over a hundred small reservoirs was used to harness the Walawe waters for paddy cultivation (Brohier, 1934). The Liyangahatota anicut, situated 24 km from the sea, diverted water to the Ridiyagama tank. Apart from the above, Arumugam (1969) has documented six other major irrigation works in the Walawe basin. After independence from the British in 1948, part of the upper basin was cultivated with tea and rubber. Around 6,000 hectares of rice lands were cultivated in the lower reach. Much of the balance was thought to be available for cultivation if the water from the Walawe could be harnessed. Three major reservoirs were proposed on the Walawe basin: the Udawalawe, Chandrikawewa and Samanalawewa. Work started on the Udawalawe in 1959 and ended in 1964. The Chandrikawewa reservoir is on a tributary of the Walawe and it was first impounded in 1961. The Samanalawewa reservoir was constructed in 1987. This simulation is limited to the region of the Walawe Basin that is under the supervision of the Mahaweli Economic Agency. This region is downstream of Samanalawewa and upstream of Liyangahatota anicut.

Soils in the region are classified into two groups as Reddish Brown Upland which is highly permeable and occupies 50% of the region and Lowland Humic Clay soils which drains poorly and occupies the balance 50% (MEA, 1987, Panabokke, 1997).

The cultivation seasons are categorised as *Maha* and *Yala*. Maha commences with the second inter-monsoon rains in October and lasts through the north-east monsoon in March. Yala starts during the first inter-monsoon period and lasts through the south-west monsoon. The runoff in the Walawe during Maha is 1,390 MCM and in Yala is 812 MCM. The lower reaches receive little rain during the south-west monsoon and needs irrigation during Yala.

Rice is the predominant crop in the lower reaches of the Walawe basin. Four-month and three and a half month varieties are generally grown. Other crops cultivated in the project area paddy, chillies, onions, vegetables, groundnut, banana and sugarcane. The large land areas in the lower reaches have a large deficit of water for cultivation particularly during Yala. Farmers are encouraged to grow crops that consume less water such as banana, groundnut and onion particularly during Yala. According to the Mahaweli Authority of Sri Lanka (MASL), replacement of rice in 30% of the lands with other crops has been achieved. MASL hopes to increase this to 40%.

Figure 1 shows the water resources of the Walawe basin below Samanalawewa region. Figure 2 shows the schematic layout of the major irrigation works that were simulated. Udawalawe has a storage capacity of 269 MCM and Chandrikawewa of 27 MCM. There are many smaller tanks within the basin. The right bank canal from the Udawalawe has a flow capacity of 18 m^3/s. The left bank canal has a capacity of 28 m^3/s. The monthly variation in the inflow of the Walawe to the Udawalawe reservoir and the climatic variables are tabulated in Table 1.

HYDROLOGICAL MODEL OF THE WALAWE BASIN

A hydrological model requires estimates for demands, inflows, losses, irrigation demands and releases and the operating policies of the reservoirs. The demands consist of the domestic demands and crop demands.

The domestic demand was calculated based on the population of the area (20,000) and an estimated per capita consumption of 200 litres per day. The calculation of irrigation demands is based on the climate and cropping pattern. The cropping pattern used in this study is shown in table 2. The reference evapotranspiration (*ETo*) was calculated based on the monthly variation of temperature, relative humidity, wind speed and daily sunshine hours using CROPWAT – a computer program that follows a modified Penmon method (Miller, 1992).

$$ET_0 = c\{W\,R_n + (1-W)\,f(u)\,(e_a - e_d)\} \tag{1}$$

Where, c is a correction factor for local conditions, $(e_a\text{-}e_d)$ is the saturated vapor pressure deficit, $f(u)$ accounts for the wind during the day, R_n is the net solar radiation and W is a weighting factor that accounts for humidity and temperature variations. For each crop, the crop evapo-transpiration (ETc) was calculated as

$$ETc = k_c\ ET_0 \tag{2}$$

where, k_c, the crop coefficient was selected from Ponrajah (1984). The 75% probability rainfall (R) was calculated with the 50 years data that is available as outlined by Ponrajah (1984). Then the monthly effective rainfall (P_e) is calculated as

$$P_\varepsilon = 0.67(R - 25) \tag{3}$$

Once the ETc and P_e is calculated, the monthly irrigation requirements is calculated for each crop, then the total monthly irrigation demand is estimated.

The losses include the evaporation from the reservoir surface, the catchment and the conveyance losses in the irrigation channels. Evaporation from the water-spread area of the reservoir is calculated based on the adjusted pan evaporation and the water spread area. The water-spread area is read from the area volume curve, which may be modeled as

$$A = 6.1\,V^{0.72} \tag{4}$$

where, A is the water-spread area in square meters and V is the volume of water stored in MCM. Seepage losses is assumed to be 0.5% of the volume of water stored in the reservoir. The conveyance losses are assumed to be 35% of the water conveyed in the distribution network.

The water balance can be written based on the estimates for demands, losses, inflows and spillage as

$$S_{n+1} = S_n + I_n - D_n - L_n - Sp_n \tag{5}$$

where, S, I, D, L and Sp refer to storage, inflow, demand, losses and spillage. The suffix n refers to the current month and $n+1$ to the next.

IMPLEMENTATION OF SIMULINK MODEL

In the numerical implementation of the water balance calculations, the procedure that is followed at each time step is as follows,

1) determine pan evaporation and river inflow for next month
2) determine volume of evaporation and leakage from reservoir
3) determine the water demand for the current month
4) determine if it is possible to satisfy demand, and compute magnitude of any spills or shortages using the reservoir operation policy
5) store these values and prepare for next time step

Figure 3 shows the graphical representation of the model in Simulink. Monthly inflows into Udawalawe and monthly irrigation demands were given as inputs to the model. The following data was obtained from MEA and the MASL:

- variation of water level vs. volume of water stored and water surface area of Udawalawe and Chandrikawewa
- monthly variation of temperature, relative humidity, wind speed and daily sunshine hours
- water releases from Udawalawe reservoir from 1990 to 1996
- pan evaporation from 1994 to 1996
- cropping patterns from 1990/91 to 1993/94
- river flow data at the reservoirs from 1949 to 1994
- rainfall over the irrigation area from 1949 to 1994

The outputs required could be the monthly water releases, spills, shortages, evaporation from the reservoir, seepage losses and a suitable index to measure performance.

RESULTS

Initially the model was tested with the past data for cropping pattern available from MEA records from 1990 to 1994. Then, the results of model releases were compared with the actual releases. Figures 4 and 5 show this comparison with the actual data recorded by the MEA for the years 1991/92 and 1993/94. Overall, the model predicts the releases with an error limited to 10-30 %. Significant deviations in model predictions and actual releases in October and April may be due the shifting of planting dates. The Irrigation Engineer may accordingly alter the planting dates after considering the rainfall during the previous weeks. The model does not anticipate such interventions at present. The water stored in reservoir may also not be optimally utilized.

The results obtained from the model are comparable with the past records. This is summarized in table 2 and figures 4 and 5. Different cropping patterns were simulated with different operating policies imposed on the main reservoir: the Udawalawe. The results are tabulated in table 2. A system reliability was defined as the number of years out of the last fifty during which the entire water requirements for crops could be supplied if the chosen cropping patterns had been used through out. The system reliability is shown for various cropping patterns. It varies between 84 and 95%. Accordingly, it is shown that with optimal release of irrigation water it is possible to cultivate up to 80% of the Maha acreage during Yala. The extent to which the area under cultivation could be expanded reliably is also estimated. One of the optimal reservoir operating policies that provided high reliability for a series of test runs of the model is given in figure 6.

Some of the smaller tanks are also included in the model as buffers to store the excess water when Udawalawe is spilling. This model can be improved if the inflows to the smaller tanks are included. In the future, water demands for hydropower and industries may also have to be incorporated. The conveyance efficiency of the distribution network, which is assumed as 65% is to be verified, particularly after the rehabilitation of the canals and structures.

The quantitative estimates provided by the model for all the details of hydrology can be used for studies in river chemistry, hydrodynamics and biology. It is quite straightforward to operate this model on a shorter time step and to expand it to cover larger irrigation networks.

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Table 1: Climatic data for the Walawe irrigation area (MEA and MASL records).

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Average Temperature (°C)	26.0	26.4	28.1	27.7	28.7	28	28	28.7	27.2	28.1	26.8	26
Relative Humidity (%)	79	78	67	78	70	74	70	68	76	76	82	80
Average Sunshine Hours (Hours / Day)	6.5	6.9	8.3	5.2	8.5	6.6	5.4	7.6	5.8	5.4	6.2	7.3
Pan Evaporation (mm/month)	98	102	126	111	106	104	169	144	153	97	105	94
75% Probability Rainfall (mm)	3	14	63	86	43	13	8	10	29	100	134	63
Reference Evapotranspiration (mm/day)	4.1	4.4	5.9	4.4	6.2	5.7	3.5	4.2	5.3	4.7	4	4.2
Mean Monthly Inflow at Udawalawe (MCM)	82.8	57	89.8	134	124	86	58	48	52	84	134	14

Table 2: Cropping Patterns and System Reliability. Asteriked sets denotes historical MEA records. Other sets are hypothetical cropping patterns that were also simulated.

Cropping Pattern	Land Allocation (ha)				System reliability
	Total Land	Maha		Yala	
		Paddy	Other Crops	% of Maha	
Set 1 *	14775	10715	4060	90%	91%
Set 2 *	14558	10673	3885	35%	95%
Set 3 *	15155	10480	4675	95%	88%
Set 4 *	15640	10430	5210	95%	88%
Set 5	18025	15600	2425	80%	84%
Set 6	18025	14040	3985	80%	85%
Set 7	18025	12480	5545	80%	88%
Set 8	18025	10920	7105	80%	88%
Set 9	19587	12012	7575	80%	86%

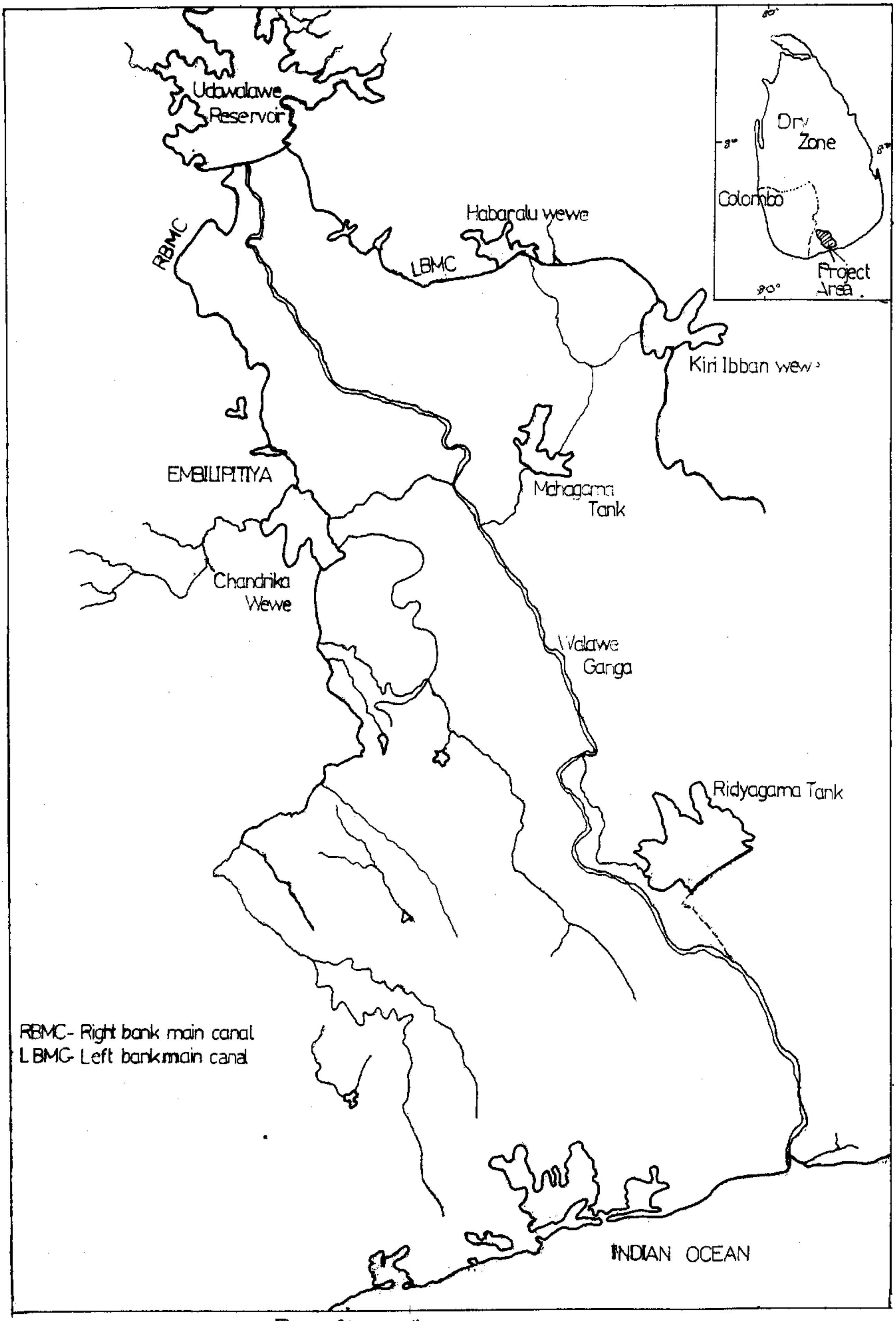

Figure 01 Location Map

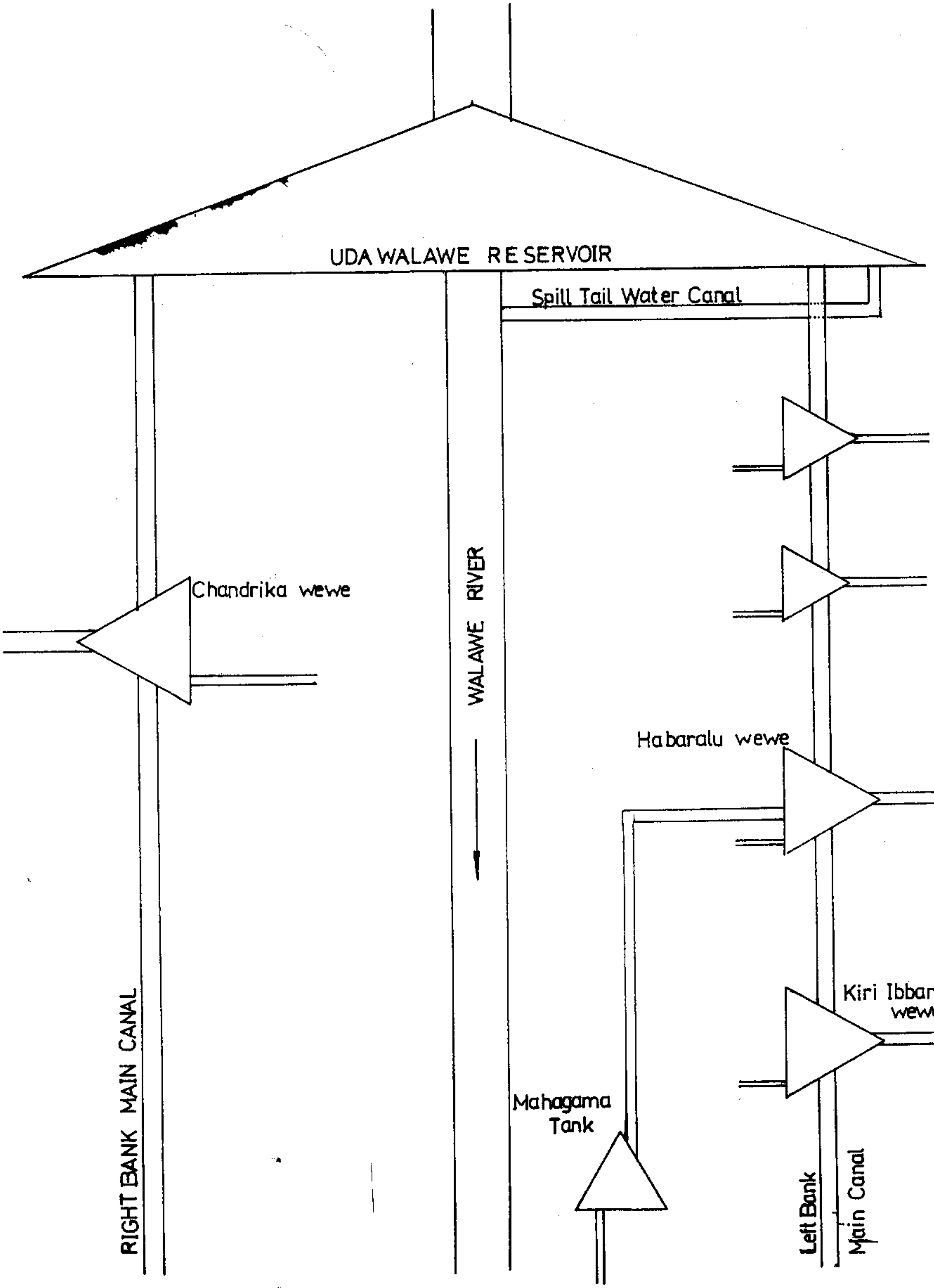

Figure 02 Schematic Layout

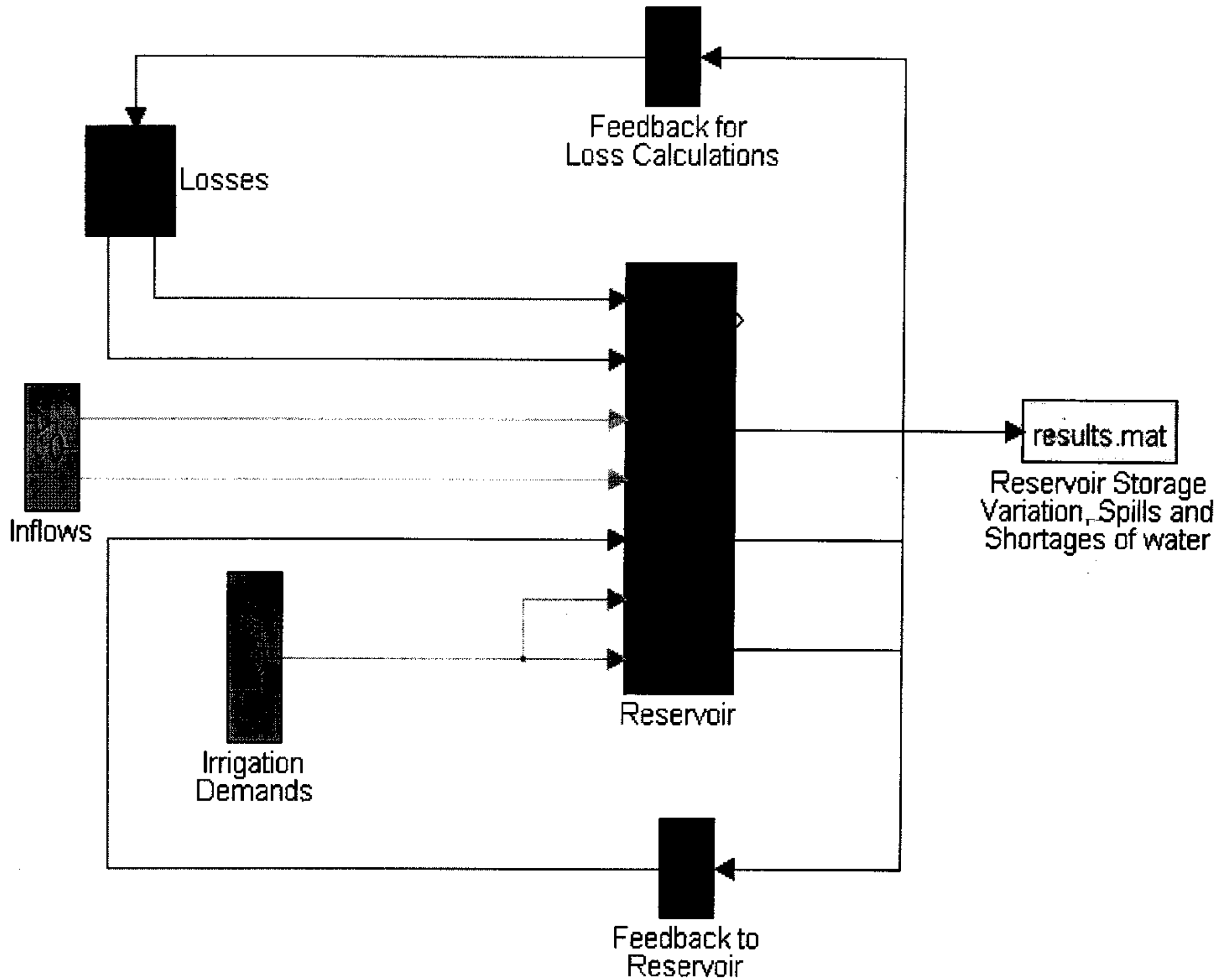

Figure 3: Schematic diagram of main components of the Simulink model. Each block shown here is composed of several other components blocks

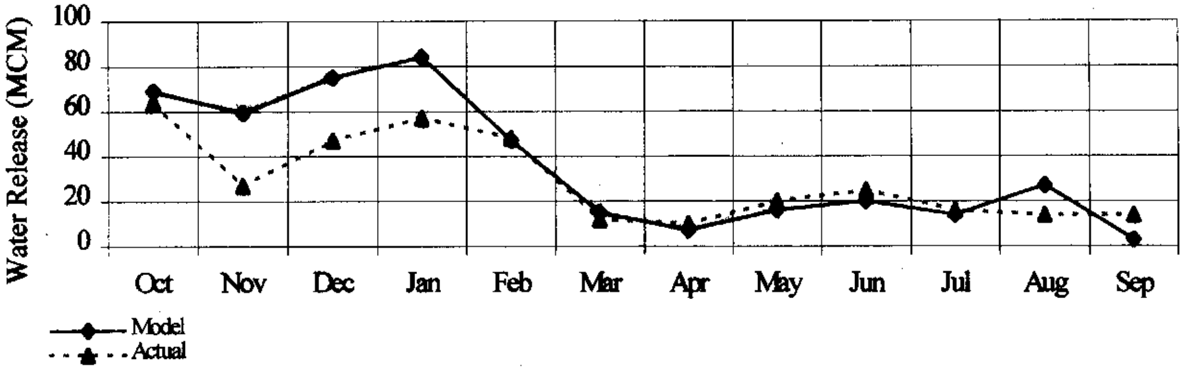

Figure 4: Water releases from Udawalawe during 1991/92 Season

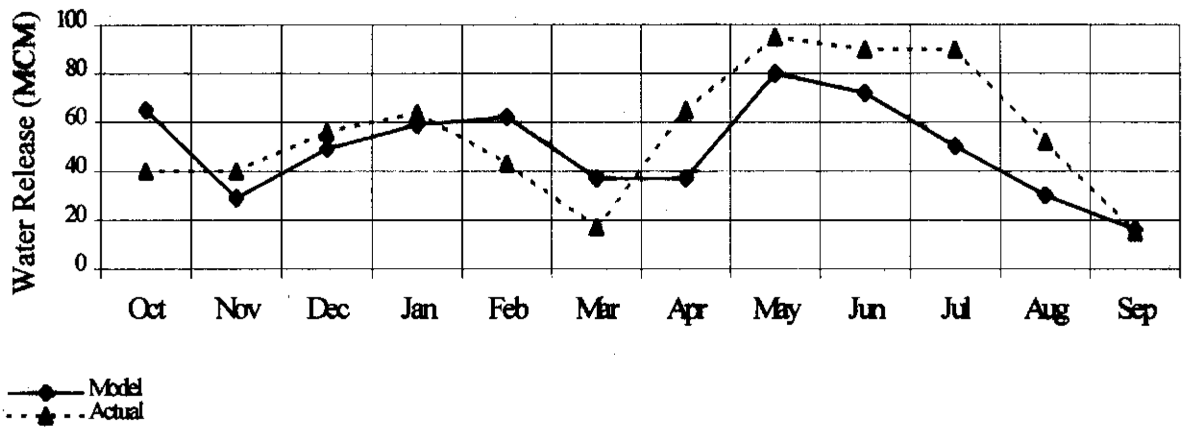

Figure 5: Water Releases from Udawalawe during 1993/94

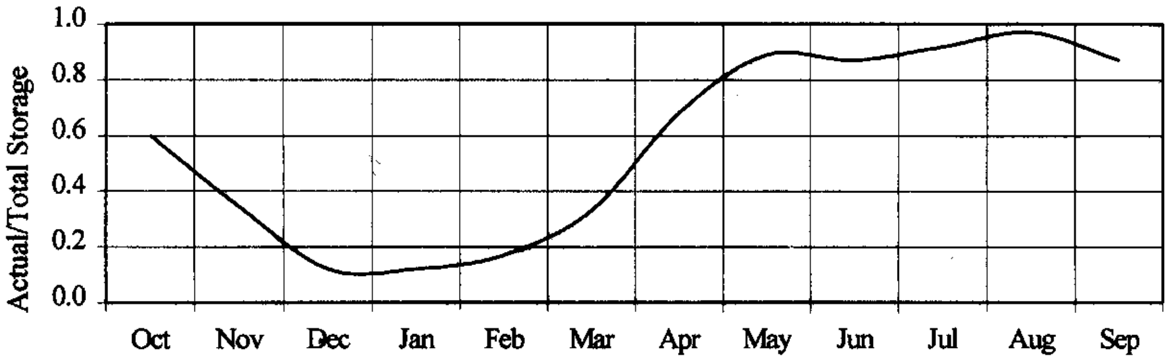

Figure 6: Reservoir operating policy for Udawalawe